63-3-1

GENERAL DYNAMICS | CONVAIR

# 401 386

Report No. 8926-136

Material - Adhesives - Structural

Effect of Bond Voids on Fatigue Strength

C. Conaway, G. D. Lindeneau, W. E. Wise



8 April 1958

Published and Distributed
under
Contract AF33(657)-8926

Post Office Box 1950, San Diego 12, California 296-6611
Material Post Office Box 2071 273-6000 | Accounting Post Office Box 510

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
SAN DIEGO

STRUCTURES & MATERIALS LABORATORIES

REPORT 57-510
DATE 3 April 1958
MODEL F-102A

TITLE

REPORT NO. 57-510
BONDING VOIDS
FATIGUE TEST
MODEL F-102A

CONTRACT NO. AF 33(600)-31174

PREPARED BY Walter Conaway
C. Conaway
G. D. Lindeneau
G.D. Lindeneau

GROUP STRUCTURES LABORATORIES

REFERENCE

CHECKED BY W. E. Wise
W. E. Wise

APPROVED BY W. E. Wise
for E. F. Strong
Chief of Test Laboratories

WITNESS:
A. C. Eulberg - Structures
V. L. Lintvedt - M & P Lab.
S. G. Gunthrop - Test Lab.
Ellis Stacy USAF

NO. OF PAGES
NO. OF DIAGRAMS

REVISIONS

| NO. | DATE | BY | CHANGE | PAGES AFFECTED |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| 88 | | | | |
| | | | | |

FORM 1812A-4

OBJECT:

This series of tests was conducted to determine the fatigue resistance of:

1. Bonds that contained voids.
2. Bonds that had been repaired by injecting adhesive into the unbonded area.

SPECIMENS:

The specimens were fabricated in accordance with Drawing 8-01672 (Reference Figures 1A - 1D). Specimens No. 1 through 16 were revisions (Reference Figure 1C) of the original type and were given the designation -40, except for No. 3 and 4 which were modified -19 assemblies.

Specimens No. 17 through 26 were -31 to -35 assemblies (Reference Figure 1B). Specimens No. 27 through 29 were -21 assemblies (Reference Figure 1D).

Specimens No. 30 - 63 were -1 through -19 assemblies (Reference Figure 1C).

Information regarding their fabrication beyond that given in Figures 1A - 1D is available in the files of the Materials and Processes Laboratories.

PROCEDURE:

The specimens were mounted in Sonntag Fatigue Testing Machines and cycled to failure except in a few instances where the number of cycles exceeded two million. Some of these specimens were dissected to see the nature of the void or the repair. Other specimens were carried on to failure at several million cycles.

Specimens of each of the three types of loading were tested as follows:

(1) Tension Nos. 1 through 16 were tested in a 1-UA Sonntag Fatigue Testing Machine (Reference Figure 2).

(2) Bending 17-26 (Reference Figure 3) and diagonal 27-29 (Reference Figure 4) in a 10-U Sonntag Fatigue Testing Machine.

(3) Specimens No. 30-63, tension type (Reference Figure 2) were tested in a 20-U Sonntag Fatigue Testing Machine.

PROCEDURE (Continued)

The diagonally loaded specimens were "stub-metered" to survey the voided areas. They were cycled and "stub-metered" at convenient intervals to observe any change or growth of the voids.

Void detection by this method was only approximate as foaming and partial adhesion confused the pattern.

The bond allowable used in the beginning was 2,000 psi. This was increased to 4,000 psi for the later specimens. The fatigue load applied was 4/9 of the above values.

All the specimens were loaded 100% maximum to 0 + 2% minimum except the diagonal specimens (Reference Figure 4) which were fully reversed + 100% maximum to -100% minimum.

The rate of cycling was 1,800 cycles per minute.

RESULTS:

The results are listed in the accompanying tables:

Summary of Table I

The cycles at failure for 1.0 $in^2$ area of adhesive metal bond loaded in shear to 4/9 of 8,000 pounds (3,555) was 56,000 $\pm$ 50% average (Reference Specimens No. 1-4).

The cycles at failure of bonds with 1.0 $in^2$ net area but with voids which increased the perimeters of the bonds varied from 166,000 cycles to 2,694,000 cycles (Reference Specimens No. 4 - 8 and 12 - 14).

Summary of Table II

The bending and diagonally loaded specimens produced no void propagation or growth.

Summary of Table III

These tests are listed to indicate that none of the bond and void combinations or injection repairs significantly influenced the fatigue life of this group.

Summary of Table III (Continued)

The bond to metal ratio used in the early stages of these tests net area of bond in shear 9.60 $in^2$/net area of metal in tension .375 $in^2$ = 25.6/1 was too great as the metal failed. When the ratio was reduced to 19.5/1 the failures appeared in both metal and bond. A safe limit and with stress concentrations minimized to assure bond failures would be somewhat less than the latter figure.

CONCLUSIONS:

While the results of these tests are not conclusive they are informative in the following regards:

1. Bond endurance depends on bond primeter as well as area; longer perimeters with a given area produce longer life within certain limits.

2. Study voids did not expand or propagate under repeated load.

3. Repairable contamination voids are extremely difficult to produce as the contaminating substance is hard to extract when repair is to be made.

4. "Stub-meter" survey of voids is only an approximation of type and size.

5. Many possible refinements of adhesive metal bonding became evident during this testing: favorable orientation of bond edges, control of elasticity of adhesives, uniformity of pressures during curing and reduction of stress concentrations that induce either bond or metal fatigue.

6. Injection repair of voids is effective where the injected adhesive spreads throughout the voided area.

7. The ratio of bond area in shear to metal cross-sectional area in tension should not exceed 18 to 1 for fatigue tests.

NOTE:

The test data from which this report was prepared are recorded in Structures Test Laboratory Data Book No. 4056, pages 10 and 11.

| REVISION | | | | |
|---|---|---|---|---|
| EFF SN | INCP | SYM | DESCRIPTION | DATE APPROVED |
| -40 | MPK | F | CHANGE IN BONDING AREA | CONVAIR COMPANY |

PAGE A
REPORT NO. 57-510
DATE 8 April 1958

9. ⚠ CONAL. PART - MINNESOTA MINING MFG. CO, ST. PAUL, MINN.
8. -19 ASSY. TO BE MADE WITH .018-.085 ADHESIVE THICKNESS AT EACH BOND, OVER ENTIRE BOND AREA. CHECK WITH ADHESIVE LAB, ENGINEERING TEST LABORATORIES FOR METHOD
7. -7-9-15-17-27-25-31 & -39 ASSY'S TO BE INJECTION REPAIRED BY THE FOLLOWING PROCEDURE:-
   (a) DETERMINE OUTLINE OF VOID BY STUB METER.
   (b) DRILL #40 INJECTION & BLEED HOLES THRU' UNBONDED METAL ONLY, MAINTAIN A MINIMUM OF .25 EDGE DISTANCE AND PLACE HOLES SO AS NOT TO INTERFERE WITH ANY SUBSEQUENT RIVETING IN THE AREA.
   (c) INJECT EC1469 UNDER PRESSURE UNTIL IT FLOWS FROM BLEED HOLES.
   (d) CLAMP UP ENTIRE AREA OR USE WEIGHTS FOR BONDING PRESSURE. USE PADS TO DAMAGE TO PART & PROVIDE MEANS FOR EXCESS RESIN TO ESCAPE FROM BLEED HOLES.
   (e) CURE REPAIR AT 300°F FOR 45 MINUTES.
   (f) REINSPECT REPAIR FOR REMAINING VOIDS.
6. -5-23 & -35 ASSY'S TO BE MADE WITH VOIDS CREATED TO SIMULATE CONTAMINATED OR FOREIGN MATERIAL IN THE BOND AREA. CHECK WITH ADHESIVE LAB., ENGINEERING TEST LABORATORIES FOR METHOD.
5. -3-29 & -33 ASSY'S TO BE MADE WITH VOIDS CREATED TO SIMULATE A CONDITION OF UNEQUAL BONDING PRESSURE. CHECK WITH ADHESIVE LAB., ENGINEERING TEST LABORATORIES FOR METHOD.
4. -1-21 & -31 ASSY'S TO BE MANUFACTURED WITHOUT VOIDS.
3. 2024 BARE SHEET QQ-A-355 HEAT TREATED TO T86 CLAD VALUES PER AN-A-48.
2. PERFORATED HONEYCOMB CORE ⅜" HEXCELL .0015 FOIL SPEC. MIL-C-7438B TYPE IC.
1. FABRICATE PER CONVAIR SPEC. B-01919.

TEST PROGRAM

| ASSY. DASH NO. | QTY | TEST |
|---|---|---|
| -1, -19, -21, -31 | 2 EA. | STATIC TO DEVTE. LOAD BY METHOD SHOWN |
| -1, -3, -5, -7 -9, -11, -13, -15 -17, -19, -21, -23 -25, -27, -29, -31 -33, -35, -37, -39 | 4 EA | FATIGUE WITH LOADS SHOWN |

8-01672
1 4

| | PART | MATERIAL | METHOD | FINAL | MATL SPEC |
|---|---|---|---|---|---|
| (A) ADHESIVE (CVAC "CEM 100-1) | | | | | |
| -19 ASSY | | | | | |
| -23 ASSY | | | | | |
| -29 ASSY | | | | | |
| -35 ASSY | | | | | |
| -5 ASSY | | | | | |
| -3 ASSY | | | | | |
| -53 PLATE | .125 X 5.0 X 10.6 | 2024 AL. ALY | | T86 | QQ-A-362 |
| -51 PLATE | .064 X 5.0 X [illegible] | 2024 AL. ALY | | T86 | QQ-A-362 |
| -49 CORE | (SEE NOTE 2) | | | | |
| -47 SKIN | .085 X 4.0 X 10.0 | 2024 AL. ALY | | T86 | QQ-A-362 |
| -45 CORE | (SEE NOTE 2) | | | | |
| -43 SPACER | .375 X .75 X 2.0 | [illegible] AL. ALY | | T8 | QQ-A-267 |
| -41 SKIN | .025 X 6.0 X 6.0 | 2024 AL. ALY | | T86 | QQ-A-362 |

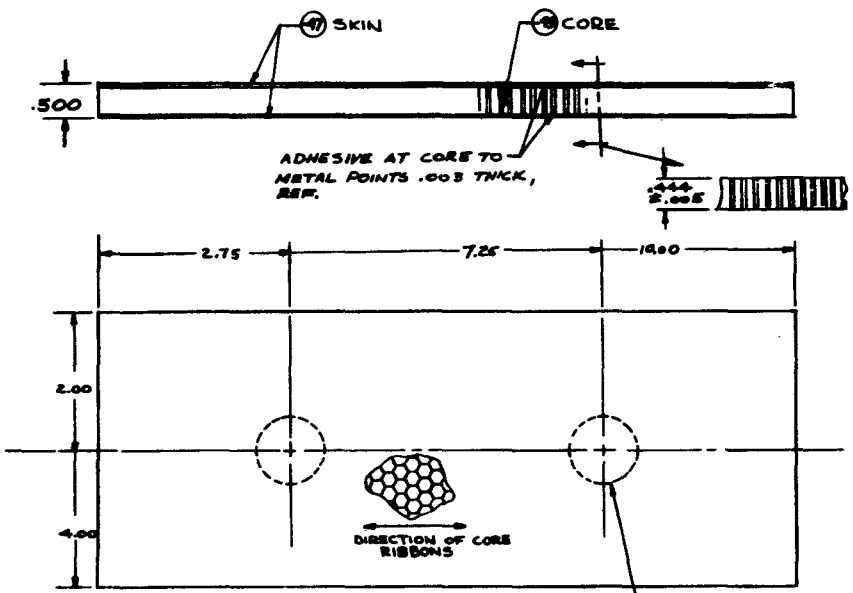
APPLICATION CONT ON SHEET 2

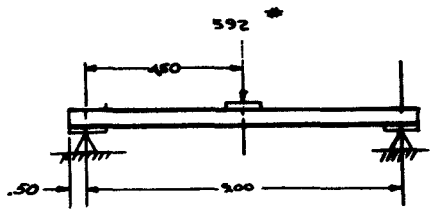
FOR TEST

TEST SPECIMEN
BONDING VOID
FATIGUE

8-01672
1 4

FIG-1A




FATIGUE LOADING

8-01672
2 4

-31 THRU 39 ASSY'S

CREATE A 1.00 DIA. BONDING VOID BETWEEN CORE AND SKIN UPPER AND LOWER SURFACES 2 PLCS. FOR -33 PER NOTE #5 AND -38 PER NOTE #6. SEE NOTE #7 FOR -37 & -39

SEE SHT 1 FOR B/M

APPLICATION CONT ON SHEET 3

FOR TEST

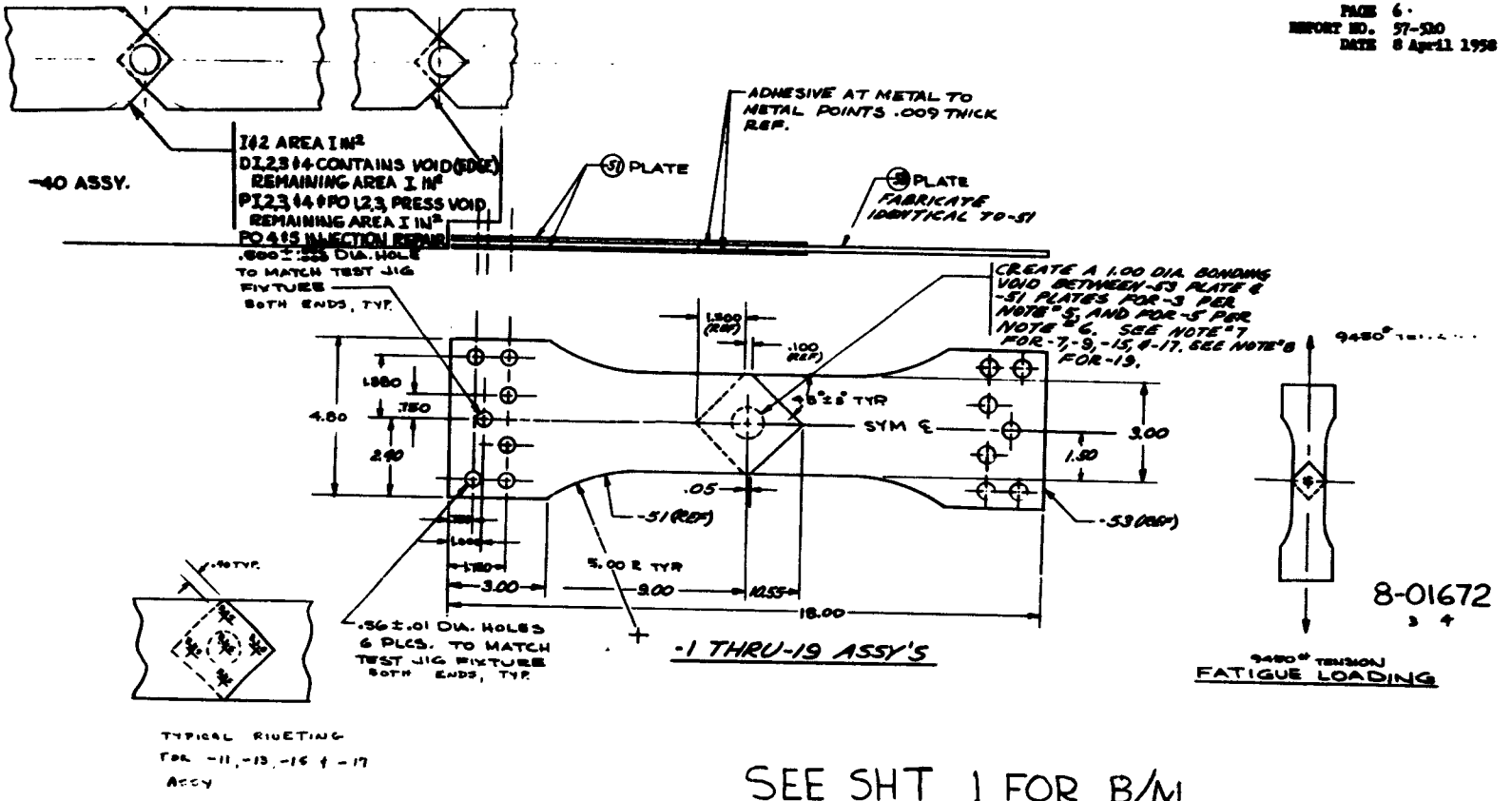
| | | |
|---|---|---|
| -27 | 4 | 4 |
| -25 | 4 | 4 |
| -23 | 1 | 1 |
| -21 | 6 | 6 |
| -19 | 6 | 6 |
| -17 | 1 | 1 |
| -15 | 4 | 4 |

| | | |
|---|---|---|
| Hammond | 4/11/7 | TEST SPECIMEN |
| Eubanks | 6-26 | BONDING VOID, |
| J. WILSON | 6-26 | FATIGUE |

FULL

8-01672
2 4

FIG.-18



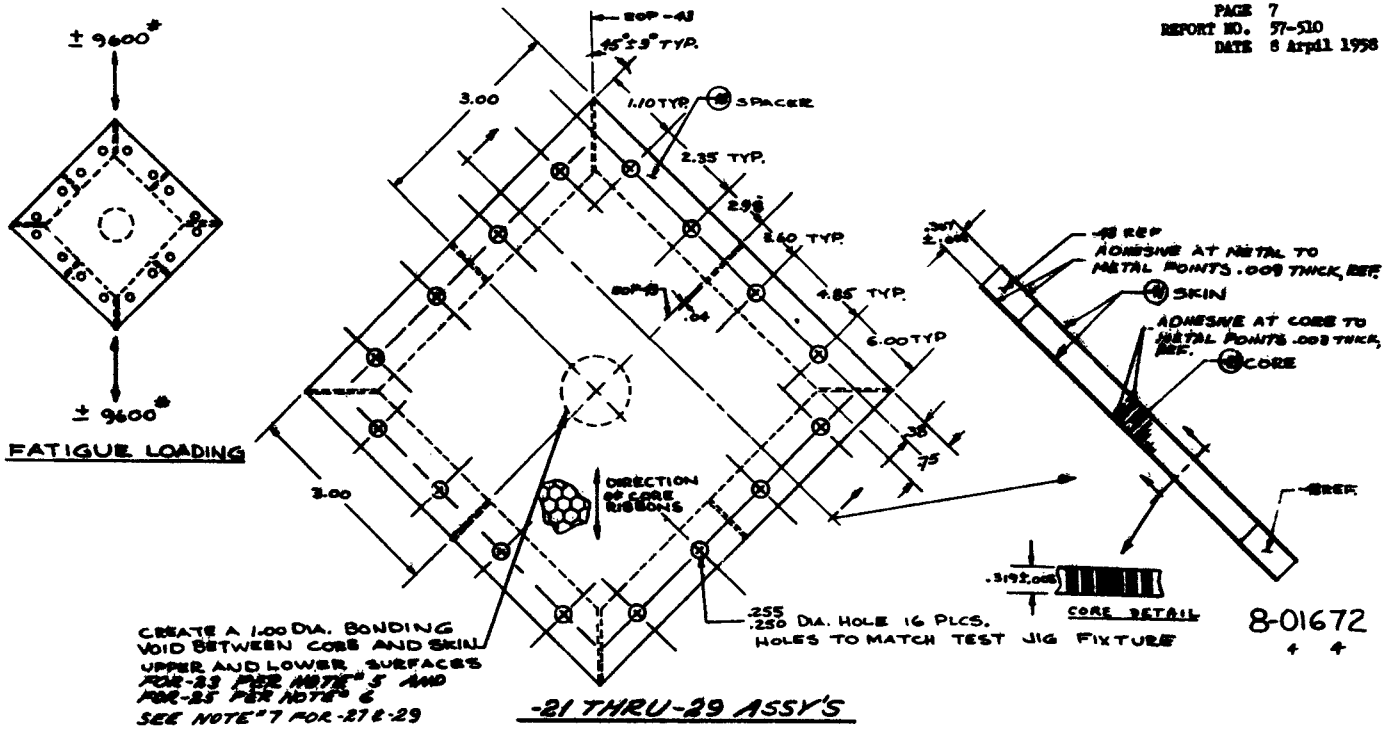

SEE SHT 1 FOR B/M

| | | |
|---|---|---|
| -39 | FOR TEST | 1 |
| -37 | | 1 |
| -35 | | 1 |
| -33 | | 1 |
| -31 | | 6 |
| -29 | | 4 |

TEST SPECIMEN
BONDING VOID,
FATIGUE

| | | |
|---|---|---|
| Manson | 4/21/7 | |
| Building | 6-26 | |
| J. WILSON | 6-26 | HALF |

8-01672
3 4
FIG-1C




8-01672
4 4

TEST SPECIMEN
BONDING VOID
FATIGUE

8-01672
4 4

FIG-1D

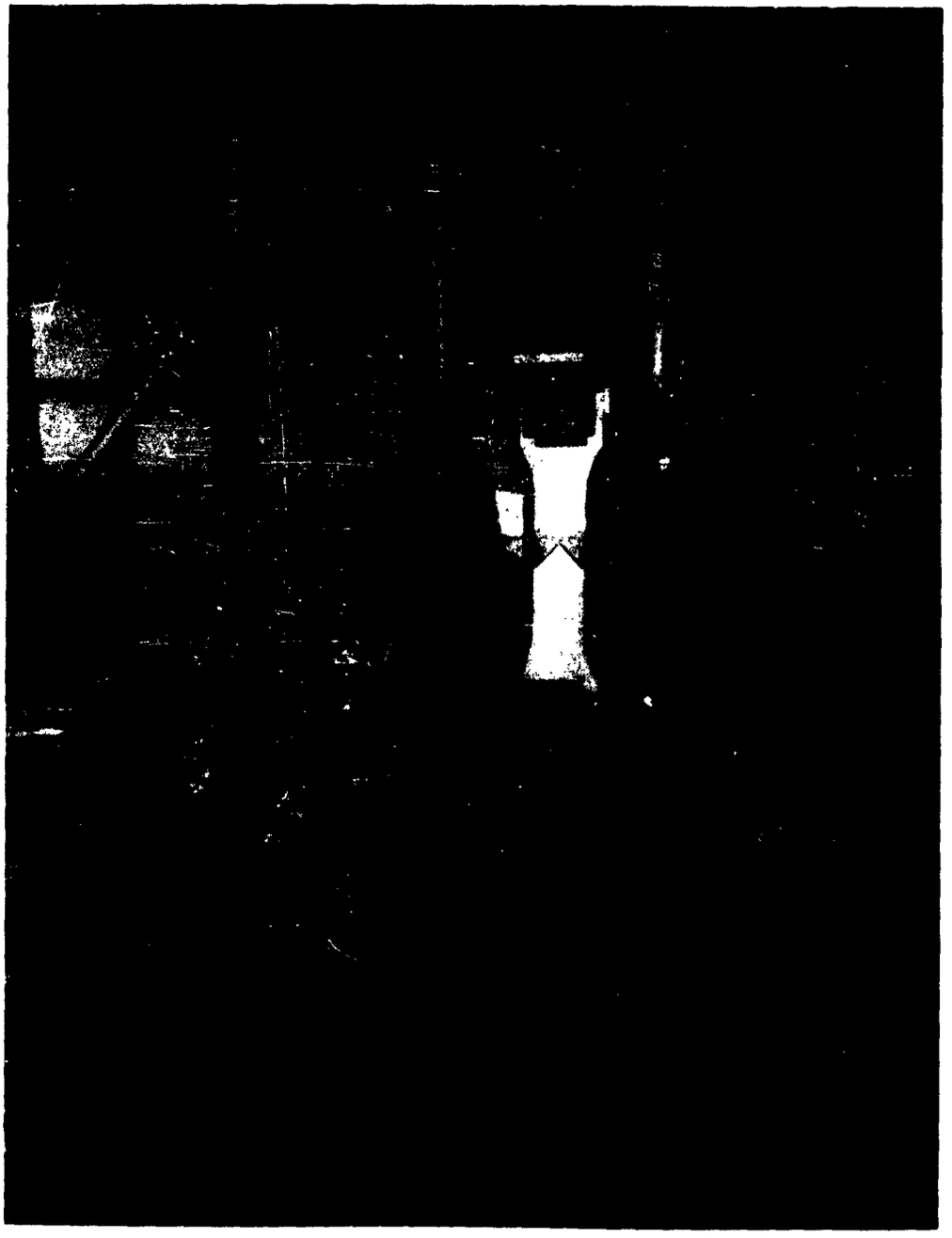


Figure 2 TENSION TESTS

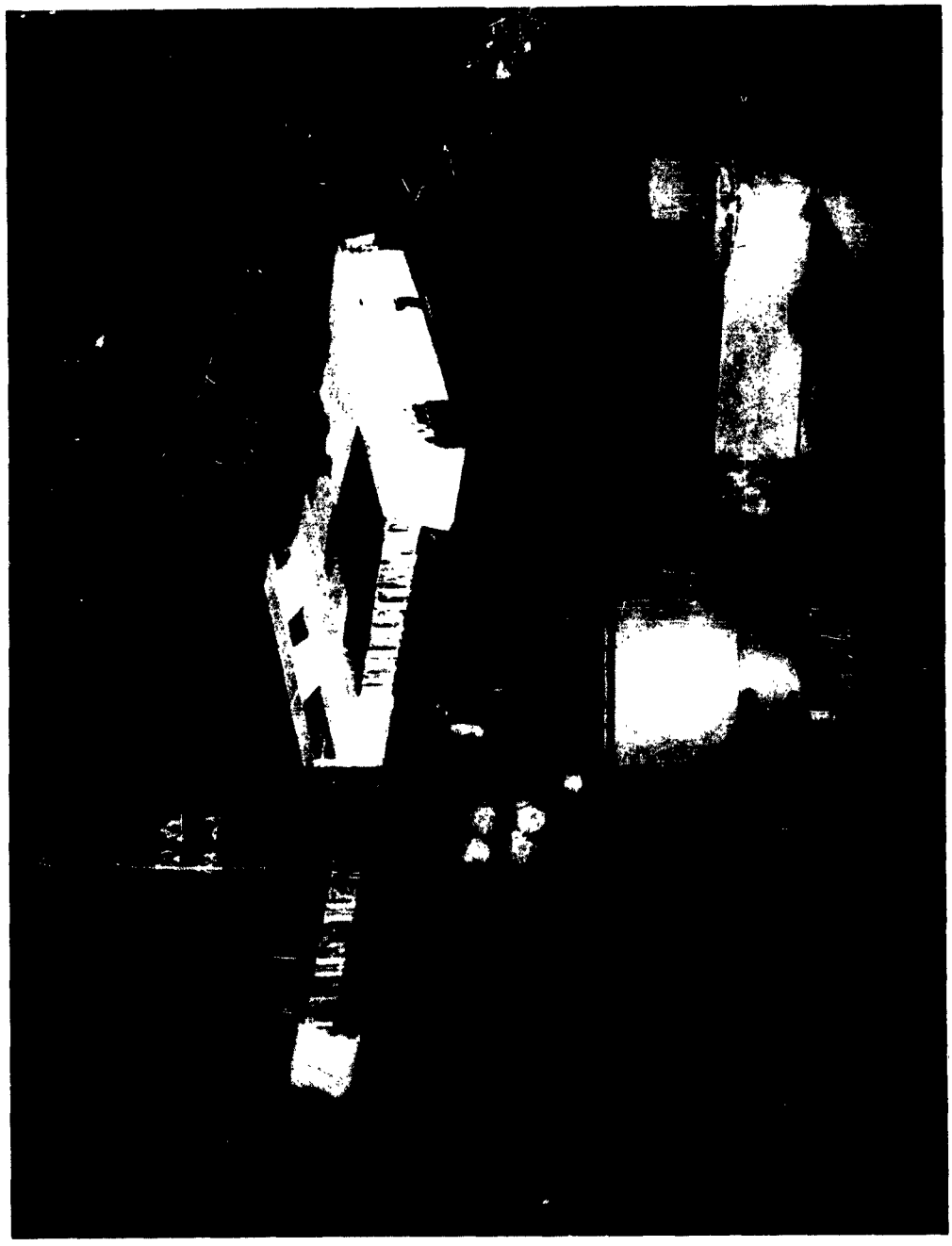


Figure 3 BENDING TESTS

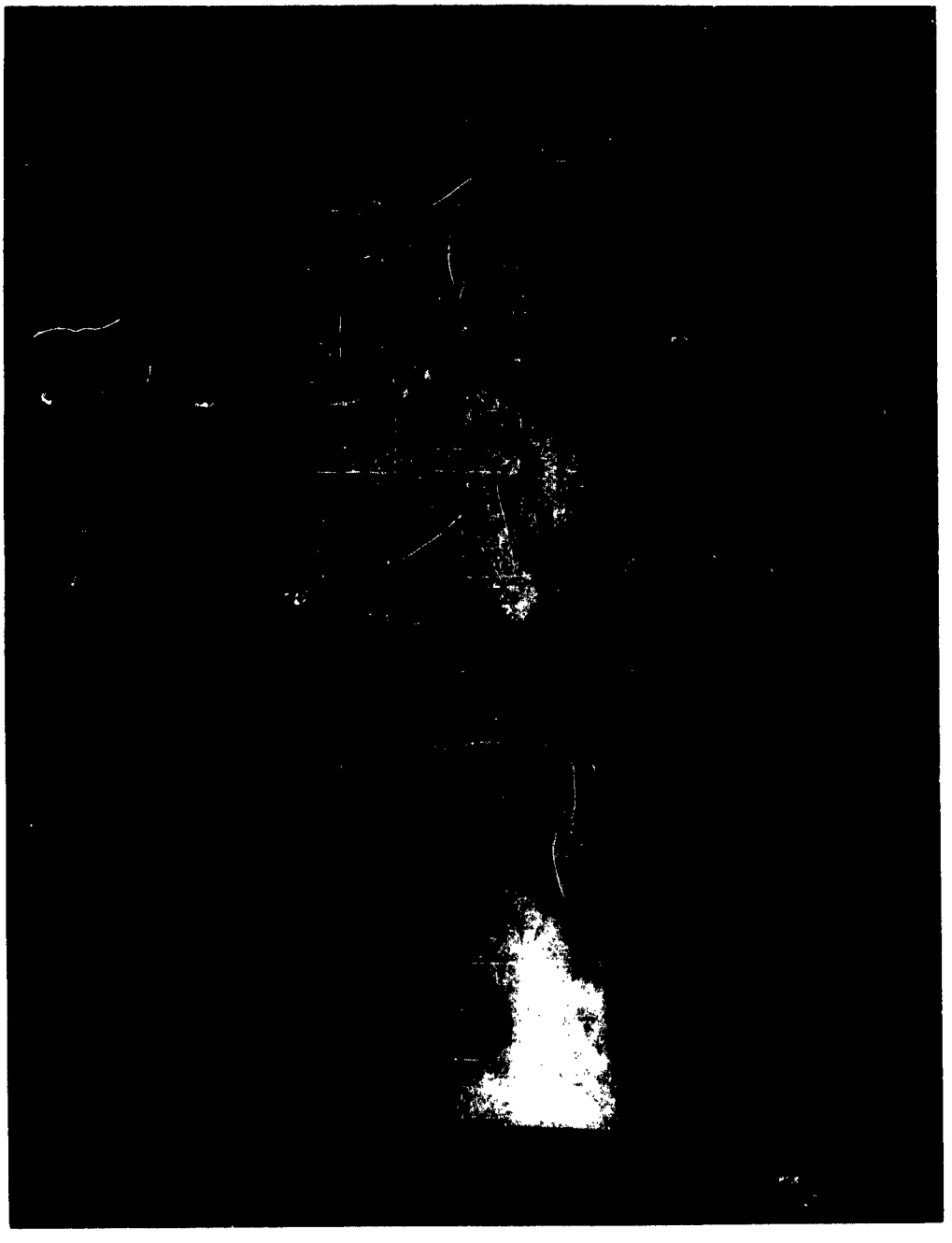


Figure 4 DIAGONAL TESTS

TABLE I

TENSION TEST RESULTS

| SPECIMEN NO. | SPECIMEN TYPE | LOADING | BOND ① PERIMETER | BOND ② AREA | BOND ②/① | LOAD TOTAL | LOAD P.S.I. | R | CYCLES TO FAILURE | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -40 | TENSION | 8 | 2 | 4 | 3555 | 1770 | .02 | 33,000 | |
| 2 | -40 | | 〃 | 〃 | 〃 | 〃 | 〃 | | 77,000 | THESE 4 SPECIMENS |
| 3 | -19 | | 8.68 | 7.35 | 1.18 | 13,830 | 1880 | | 79,000 | WERE WITHOUT VOIDS |
| 4 | 〃 | | 〃 | 〃 | 〃 | 13,070 | 1770 | | 62,000 | |
| 5 | -40 D1 | | 12.68 | 2 | 6.34 | 3555 | 〃 | | 166,000 | THESE 4 SPECIMENS |
| 6 | D2 | | 〃 | 〃 | 〃 | | 〃 | | 2,694,000 | HAD VOIDS MANFACTURED |
| 7 | D3 | | 〃 | 〃 | 〃 | | 〃 | | 2,570,000 | IN THE EDGE OF THE BONDS |
| 8 | D4 | | 〃 | 〃 | 〃 | | 〃 | | 1,845,000 | |
| 9 | P1 | | 12 | * | ** | | ** | | ∞ | THE VOIDS OF THESE 3 |
| 10 | P2 | | 〃 | 〃 | 〃 | | 〃 | | 〃 | SPECIMENS INADVERTENTLY |
| 11 | P3 | | 〃 | 〃 | 〃 | | 〃 | | 〃 | BONDED. |
| 12 | P01 | | 〃 | 2 | 6.00 | | 1770 | | 184,000 | VOIDS OF THESE 3 SPECIMENS |
| 13 | P02 | | 〃 | 〃 | 〃 | | 〃 | | 1,499,000 | WERE MANUFACTURED |
| 14 | P03 | | 〃 | 〃 | 〃 | | 〃 | | 355,000 | WITHIN THE BONDS. |
| 15 | P04 | | 〃 | * | ** | | ** | | ∞ | VOID REPAIRED BY INJECTION |
| 16 | -40 P05 | TENSION | 〃 | 〃 | 〃 | 3555 | 〃 | .02 | 1,682,000 | INJECTION ONLY PARTIALLY SUCCESSFUL. |

* THESE AREAS WERE NOMINALLY 2 IN$^2$ BUT BECAME INDEFINITE.

** THESE RATIOS AND STRESSES WERE INDETERMINATE.

TABLE II

BENDING & DIAGONAL LOADING RESULTS — VOID PROPAGATION

| SPECIMEN NO. | SPECIMEN TYPE | LOADING | LOAD LBS. | STRESS* P.S.I. | "R" | CYCLES TO FAILURE | REMARKS |
|---|---|---|---|---|---|---|---|
| **BENDING** | | | | | | | |
| 17 | -31 | BENDING | 592 | 26,620 | .02 | 2,687,000 | THE VOIDS IN THESE SPECIMENS DID NOT PROGRESS UNDER REPEATED LOAD. |
| 18 | | | | | | 946,000 | |
| 19 | | | | | | 650,000 | |
| 20 | | | | | | 745,000 | |
| 21 | | | | | | 2,973,000 | |
| 22 | -31 | | | | | 795,000 | |
| 23 | -35 | | | | | 805,000 | |
| 24 | | | | | | 1,413,000 | |
| 25 | | | | | | 5,299,000 | |
| 26 | -35 | BENDING | 592 | 26,620 | .02 | 1,811,000 | |
| **DIAGONAL TENSION & COMPRESSION** | | | | | | | |
| 27 | -23 | DIAGONAL | ±9600 | ± 25650 | ± 1.00 | 4,000 | NO GROWTH OF VOIDS |
| 28 | | | ±8000 | ± 21400 | | 7,000 | |
| 29** | -23 | DIAGONAL | ± 8000 | ± 21400 | ± 1.00 | 30,000 | |

* STRESS IN SANDWICH SKIN.

** THIS SPECIMEN HAD A VOID CREATED BY INSERTING A TOOL THROUGH A 1/8 IN. HOLE IN THE SKIN AND GOUGING OUT THE BOND.

TABLE III

TENSION TESTS — METAL FAILURES

| SPECIMEN NO. | SPECIMEN TYPE | AREA | LOAD LBS. | LOAD P.S.I. | CYCLES TO FAILURE | REMARKS |
|---|---|---|---|---|---|---|
| 30 | -1 | 9.60 | 9450 | 985 | 1000 | FAULTY BOND |
| 31 | | | | | 315,000 | METAL FAILURE |
| 32 | | | | | 175,000 | |
| 33 | | | | | 329,000 | |
| 34 | | | | | 216,000 | |
| 35 | -1 | 9.60 | | 985 | 148,000 | |
| 36 | -3 | 8.03 | | 1175 | 214,000 | |
| 37 | | | | | 185,000 | |
| 38 | | | | | 221,000 | |
| 39 | -3 | | | | 245,000 | |
| 40 | -5 | | | | 218,000 | |
| 41 | | | | | 250,000 | |
| 42 | | | | | 228,000 | |
| 43 | -5 | 8.03 | | 1175 | 225,000 | |
| 44 | -7 | 9.60 | | 985 | 162,000 | |
| 45 | | | | | 282,000 | |
| 46 | | | | | 162,000 | |
| 47 | -7 | 9.60 | | 985 | 304,000 | |
| 48 | -11 | 8.03 | | 1175 | 179,000 | |
| 49 | | | | | 242,000 | |
| 50 | | | | | 289,000 | |
| 51 | -11 | | | | 120,000 | |
| 52 | -13 | | | | 328,000 | |
| 53 | | | | | 270,000 | |
| 54 | | | | | 311,000 | |
| 55 | -13 | | | | 266,000 | |
| 56 | -15 | 8.03 | 9450 | 1175 | 137,000 | METAL FAILURE |

TABLE III (CONT.)

| SPECIMEN NO. | SPECIMEN TYPE | AREA | LOAD LBS. | LOAD P.S.I. | CYCLES TO FAILURE | REMARKS |
|---|---|---|---|---|---|---|
| 57 | -15 | 8.03 | 9450 | 1175 | 132,000 | METAL FAILURE |
| 58 | | | | | 219,000 | |
| 59 | -15 | 8.03 | | 1175 | 130,000 | |
| 60 | -19 | 9.60 | | 985 | 186,000 | |
| 61 | | | | | 170,000 | |
| 62 | | | | | 337,000 | |
| 63 | -19 | 9.60 | 9450 | 985 | 437,000 | METAL FAILURE |